

The Definitive Encyclopedia of Machine Learning: Master Index

Part I: The Mathematical & Statistical Bedrock

1. Linear Algebra for ML

- **Scalars, Vectors, Matrices, and Tensors:** Definitions and notation.
- **Vector Operations:** Dot product, Cross product, Norms ($\|L_1\|$, $\|L_2\|$, $\|L_\infty\|$).
- **Matrix Algebra:** Matrix-Matrix multiplication, Identity matrix, Inverse, Transpose, Trace.
- **Linear Systems:** Rank, Determinants, Gaussian Elimination.
- **Matrix Decomposition:** * Eigenvalues and Eigenvectors.
 - Singular Value Decomposition (SVD).
 - LU and Cholesky Decomposition.
 - Principal Component Analysis (PCA) Mathematical Derivation.

2. Calculus of Learning

- **Differential Calculus:** Limits, Continuity, and Derivatives.
- **Multivariable Calculus:** Partial Derivatives and Gradients.
- **The Chain Rule:** Univariate and Multivariate applications (The foundation of Backpropagation).
- **High-Order Derivatives:** The Jacobian Matrix and The Hessian Matrix.
- **Taylor Series Expansion:** Local approximation of functions.

3. Probability & Frequentist Statistics

- **Core Theory:** Bayes' Theorem; Conditional Probability; Independence.
- **Probability Distributions:** * Discrete: Bernoulli, Binomial, Poisson, Multinomial.
 - Continuous: Gaussian (Normal), Student's T, Exponential, Beta, Gamma.
- **Statistical Inference:**
 - **P-Value:** Mathematical definition, interpretation, and Significance Levels (α).
 - Confidence Intervals and Central Limit Theorem.
 - **Hypothesis Testing:** Z-test, T-test (One-sample, Two-sample, Paired), ANOVA, Chi-Square.
- **Estimation Theory:** Maximum Likelihood Estimation (MLE); Maximum A Posteriori (MAP).

Part II: Supervised Learning

4. Linear & Non-Linear Regression

- **Simple Linear Regression:** The Slope and Intercept.
- **Multiple Linear Regression:** Handling multiple features and Intercepts.

- **Assumptions of Linearity:** Homoscedasticity, Multicollinearity (VIF), Normality of Residuals.
- **Parameter Optimization: * Ordinary Least Squares (OLS).**
 - **The Normal Equation.**
 - **Gradient Descent:** Batch, Stochastic (SGD), and Mini-batch.
- **Evaluation Metrics:**
 - **Cost Functions:** Mean Squared Error (MSE), Mean Absolute Error (MAE), Root Mean Squared Error (RMSE), Huber Loss.
 - **Goodness of Fit: R-Squared (R^2) and Adjusted R-Squared.**
- **Advanced Regression: Polynomial Regression, Spline Regression, Step Functions.**
- **Regularization (Shrinkage): Ridge (L2), Lasso (L1), and Elastic Net.**

5. Classification Algorithms

- **Logistic Regression:** Logit Link Function, Sigmoid Activation, Log-Loss (Cross-Entropy).
- **Multiclass Classification:** One-vs-Rest (OvR), One-vs-One (OvO), and **Softmax Regression.**
- **Discriminant Analysis:** Linear (LDA) and Quadratic (QDA).
- **Support Vector Machines (SVM):** Maximum Margin Hyperplanes, Slack Variables.
- **The Kernel Trick:** Linear, Polynomial, **Radial Basis Function (RBF)**, Sigmoid Kernels.
- **Instance-Based:** K-Nearest Neighbors (KNN), Distance Metrics (Euclidean, Manhattan, Minkowski).
- **Naive Bayes:** Gaussian, Multinomial, and Bernoulli NB; Laplace Smoothing.

6. Tree-Based Models & Information Theory

- **Decision Tree Mechanics:** Recursive Binary Splitting, Pruning (Cost-Complexity).
- **Information Metrics:**
 - **Entropy:** Measuring Information Gain.
 - **Gini Impurity:** Probability of Misclassification (CART Algorithm).
- **Ensemble Methods:**
 - **Bagging:** Random Forests (Feature Randomness, Out-of-Bag Error).
 - **Boosting:**
 - **AdaBoost (Adaptive Boosting):** Weighting misclassified samples.
 - **Gradient Boosting (GBM):** Residual learning and Learning Rates.
 - **Optimized Boosting:** XGBoost (Regularized), LightGBM (Leaf-wise), CatBoost (Categorical).

Part III: Unsupervised Learning & Geometry

7. Clustering & Association

- **Partitioning:** K-Means and **K-Means++** Initialization.
- **Hyperparameter Tuning: The Elbow Method (WCSS), Silhouette Scores, Gap Statistic.**

- **Hierarchical Clustering:** Agglomerative (Bottom-up), Linkage (Ward, Complete, Single), **Dendrograms**.
- **Density-Based:** DBSCAN (Epsilon, MinPoints), OPTICS.
- **Association:** Apriori Algorithm, Support/Confidence/Lift.

8. Dimensionality Reduction

- **Linear:** Principal Component Analysis (PCA), Factor Analysis.
- **Non-Linear:** t-SNE, UMAP, Isomap, Kernel PCA.

Part IV: Neural Networks & Deep Learning

9. Deep Learning Foundations

- **Architecture:** Perceptrons, Multi-Layer Perceptrons (MLP).
- **Activation Functions:** Sigmoid, Tanh, **ReLU**, Leaky ReLU, ELU, Softmax.
- **The Optimization Loop:** Forward Propagation and **Backpropagation (Chain Rule application)**.
- **Neural Optimizers:** Momentum, **AdaGrad (Adaptive Gradient)**, RMSProp, **Adam**, AdamW.
- **Neural Regularization:** Dropout, Batch Normalization, Weight Initialization (Xavier, He).

10. Specialized Architectures

- **Computer Vision:** Convolutional Neural Networks (CNNs), Pooling, Strides, Padding.
- **Sequence Models:** RNNs, LSTMs, GRUs, Bidirectional RNNs.
- **The Transformer:** Self-Attention, Multi-head Attention, Positional Encoding.

Part V: The Frontier (2024-2026)

11. Generative AI & LLMs

- **Large Language Models:** GPT, BERT, T5 architectures.
- **Fine-Tuning:** PEFT (LoRA, QLoRA), Reinforcement Learning from Human Feedback (RLHF).
- **Generation Models:** GANs, VAEs, **Diffusion Models** (Latent Diffusion).
- **Retrieval-Augmented Generation (RAG):** Vector Databases, Semantic Search.

12. Reinforcement Learning

- **Foundations:** Markov Decision Processes (MDP), Rewards, States, Actions.
- **Algorithms:** Q-Learning, Deep Q-Networks (DQN), PPO, Actor-Critic.

Part VI: Engineering & Metrics

13. Evaluation & Validation

- **Classification Metrics:** Confusion Matrix, **Precision, Recall, F1-Score**, ROC-AUC Curve.
- **Validation:** K-Fold Cross-Validation, Stratified K-Fold, Leave-one-out.
- **Analysis:** Bias-Variance Trade-off, Learning Curves.

14. MLOps & Explainability

- **XAI:** SHAP (Shapley Values), LIME, Feature Importance.
- **Production:** Containerization, Model Drift, Data Drift, Ethical AI.